SUGAR MAPLE DECLINE IN ONTARIO

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Introduction

The decline of sugar maple in a rural area was first reported in Ontario in Grey County in 1952 (Griffin, 1965). Symptoms of damage included discoloured foliage and death of young twigs followed by crown dieback. The progression was slow and trees seldom died. These symptoms agreed with those reported by Kessler (1963) in Michigan. The dieback was associated with overexposure due to heavy overcutting in the stands. In addition, on dry sites, grazing by animals may have accelerated tree decline. Recovery occurred in moderately affected trees in both Ontario and Michigan.

Over the years maple decline has been observed at intervals in different parts of the Province of Ontario, with severe outbreaks occurring in 1976 and 1977 in the Parry Sound and Owen Sound districts. In this latter episode, forest tent caterpillar defoliated the forests, and over 50% of the sugar maple trees were killed on 8000 ha and 500 ha in the Parry Sound and Owen Sound areas, respectively (Canadian Forestry Service, 1980). The insect population collapsed and most of the surviving sugar maple trees recovered.

In the spring of 1984, a number of maple syrup producers from the Muskoka area of Ontario complained to the Ministry of Agriculture and Food about the increase in dieback and mortality of sugar maple trees in the last six years. The producers felt that acidic precipitation may be involved and that continued sugar maple decline could jeopardize the local maple syrup industry.

The Ontario Ministry of the Environment was asked to investigate the role of acidic precipitation in this recent maple decline outbreak in Muskoka. A field study was designed by the Phytotoxicology Section, Air Resources Branch to examine the etiology of the declining sugar maple trees. Questionnaires were given to each woodlot owner to provide a history of stand management. Permanent observation plots were established in seven woodlots in the Muskoka area of south-central Ontario and in one woodlot near Thunder Bay in northwest Ontario. Soil from the woodlots and foliage, twigs and roots from sugar maple trees exhibiting a gradient of decline symptoms were collected for chemical analysis. Increment

cores were collected from sampled trees and discs were taken from felled trees to examine chronological growth patterns. In addition, atmospheric acidic deposition rates, forest management practices, the presence of disease and the history of insect defoliation, site disturbance, tree age, site quality and weather records were investigated at each study site location.

This report briefly describes the field methodology and presents a summary of preliminary results. A final report of the 1984 field research study is under preparation and will include greater detail on methods, site descriptions and discussion of all results.

Study Sites

The study was conducted at eight sites, seven in Muskoka and one near Thunder Bay. Only five of the Muskoka woodlots had a history of management for maple syrup products. The sites were chosen in consultation with the Ontario Maple Syrup Producers Association and the Ontario Ministry of Agriculture and Food to represent a gradient of decline symptoms. Their geographical range extended from just north of Gravenhurst to Sundridge and from Gibson just east of Georgian Bay to Dorset. These sites were located within the Georgian Bay Section of the Great Lakes - St. Lawrence Forest Region, as defined by Rowe (1972). The Thunder Bay site was approximately 30 km NW of the city and was situated within the Quetico Section of the Great Lakes - St. Lawrence Forest Region. All sites were mature hardwood forests and contained sugar maple as the dominant tree species. Associated tree species included red maple, white ash, American beech, black cherry, white and yellow birch and occasionally hemlock.

Ground and aerial observations revealed that maple decline was scattered throughout Muskoka in various degrees of severity. Severe decline occurred in scattered, isolated pockets and more frequently on higher exposed sites. However, this pattern was not consistent. Occasionally, a few severely affected trees were observed distributed among healthy trees in an otherwise unaffected woodlot. On other sites most of the mature sugar maple over several hectares exhibited thin but normally green-coloured crowns. Similar decline symptomatology has been observed in sugar maple stands near Thunder Bay and elsewhere in Ontario on calcareous soil sites.

Atmospheric monitoring in Ontario has determined that the Muskoka region receives about 35 kg/ha/yr total wet sulphate deposition. Acidic deposition in the northwestern (Thunder Bay) section of the province is approximately 8

kg/ha/yr. For this reason the Thunder Bay site was originally intended as an "acid rain control" area.

Relative Decline Index

A detailed numerical rating system was designed to identify symptoms typically attributed to sugar maple decline. The rating system included observations of the number of dead branches, the percentage of the crown displaying undersized and discoloured foliage, and the presence of faults such as cracks, tap holes, cankers, fungal fruiting bodies and other wounds. Basic mensurational data were also recorded.

A 20m x 20m permanent observation plot was established at each of the 8 study sites and every tree greater than 10 cm DBH was rated using the numerical decline index. A tree with a decline index score of less than 15 was considered essentially healthy, a score of 16 to 35 denoted a tree exhibiting light to moderate decline symptoms, and a severely affected tree scored greater than 35.

When the data from the seven Muskoka study sites were combined, using the numerical decline index, 58% of the trees were considered healthy, 20% had light to moderate decline symptoms, and 22% exhibited severe maple decline. The decline gradient was similar for trees from the Thunder Bay site although a slightly higher percentage (68%) were in the healthy category.

There was no apparent relationship between the average decline index of each study site and stand stocking, basal area or total plot biomass. However the decline index was related positively and significantly with diameter breast height ($t = 2.748$, $p \leq 0.01$) and can be described with the regression line equation Decline Index = 21.719 + 0.112 Diameter Breast Height. Therefore, it would appear that tree size or age was a predispositional factor to tree decline. These data are summarized in Table 1.

At least one half of the trees had at least one trunk fault or wound. There was a tendency towards a higher decline index on faulted trees. The average decline index of sugar maple trees which were free of trunk faults and had not been tapped for maple syrup production was 20.6. The average decline index of the trees which had not been tapped but had at least one trunk wound was 19.4. Trees which were both tapped and wounded had a mean decline index of 31.9. However, trees which had been tapped but were otherwise fault-free had an average decline index of 33.2.

Soil Characteristics

At each of the eight study sites a soil pit was dug to classify the soil and determine its sensitivity to acidic precipitation as it may relate to tree decline. The site was described according to the guidelines prescribed by the Ontario Institute of Pedology, University of Guelph (1982). The soil was described and classified by the "System of Soil Classification of Canada" (Canadian Department of Agriculture, 1978). Soil samples collected from horizons in each pit were air-dried, disaggregated, ground and sieved to two size fractions and analyzed for the following parameters: pH (both H_2O and $CaCl_2$); exchangeable calcium, magnesium, potassium and aluminum; cation exchange capacity (CEC); base saturation (BS); pyrophosphate and dithionite extractable iron and aluminum; organic carbon; total carbonates; total nitrogen; extractable aluminum and sulphate; heavy metals (copper, nickel, lead and zinc) and texture. A summary of some of these analyses (mineral soil samples) from each study site is listed in Table 2.

The soils in the Muskoka area have developed on coarse textured glacial till material. The major rooting zone within the profiles rarely exceeded 40 cm in depth. Profiles consisted of a thin (less than 10 cm) surface horizon (Ah) rich in organic materials underlain by well-defined mineral horizons. Subsurface horizons (Bf, Bhf) were enriched with iron and aluminum.

All seven Muskoka soil sites were classified as naturally acidic podzols. The mean pH was 4.8 with soil pHs ranging from 4.0 to 5.3. The cation exchange capacities were very low averaging 1.4 and ranging from 0.4 to 3.2. Base saturation varied from 4.4% to 60%. Soluble aluminum ($CaCl_2$ extracted) concentrations varied from a low of 5 ppm to a high of 33 ppm. No $CaCo_3$ was detected at any of the Muskoka soil sites. The soil characteristics of the Thunder Bay site were considerably different from the Muskoka sites, thereby limiting the use of Thunder Bay as a control location.

According to Cowell et al (1981) and Wang and Coote (1981) podzolic soils contain the lowest amounts of bases and are the most susceptible (with regard to tree growth) due to base element deficiencies and aluminum toxicity problems. In contrast, the less acidic brunisolic soil (Thunder Bay) may be more sensitive to changes in soil pH due to acidic precipitation. Linzon and Temple (1980) found that podzolic soils with low pHs in the Parry Sound area of Ontario were not pH-altered by acidic precipitation over an 18 year period from 1960 to 1978, whereas a brunisolic soil with an intermediate pH became more acidic.

Soils with pH values greater than 6.5 are in the carbonate buffering range. Soils in the 5.0 to 6.5 pH range are in the silicate buffering range whereby mineral weathering offsets changes in soil solution pH. Soils with pH 4.2 to 5.0 are in the cation exchange buffering range where clay particles provide active exchange sites. Soils with a pH of less than 4.2 are buffered by aluminum hydroxides (Tomlinson, 1983). The Muskoka soils lie primarily within the cation exchange and aluminum buffering range. Due to the coarse texture of the soils, the main source of cation exchange would be organic colloids, the majority of which are located in the thin surface horizon above the active rooting zone. Because of the acidic nature of the Muskoka soils, aluminum will be available to plants. In contrast, the Thunder Bay soil is only slightly acidic and also has a trace amount of carbonates. Carbonates will neutralize incoming acidity and maintain soil pH at a level that prevents aluminum from becoming soluble.

Wang and Coote (1981) classified soil sensitivity (with regard to tree growth) on base content, using the product of cation exchange capacity and base saturation (< 6 meq/100 gm exchangeable bases = sensitive, 6-15 meq/100 gm= moderately sensitive and >15 meq/100 gm = non-sensitive). Based on these criteria all seven Muskoka sites are classified as "sensitive" and the Thunder Bay site as "moderately-sensitive".

These data suggest that the potential exists for soil characteristics in the Muskoka area to contribute to the mechanisms of tree decline.

Tissue Chemical Concentrations

Foliage, twigs and roots were collected from trees displaying a gradient of decline symptoms from each of the eight study sites. In addition, soil samples were taken from around each of the sampled trees. All samples were analyzed for the following elements; Fe, Mn, P, N, Al, B, Ca, Cd, Cl, Co, Cr, Cu, F, K, Mg, Mo, Na, Ni, Pb, S, V and Zn. The premise was to compare chemical concentrations between healthy and declining tree populations.

Foliar samples were collected in early August, labelled, placed in polyethylene bags and stored under refrigeration until they were processed (not-washed and oven-dried). Analysis was performed by either ICAP or AAS, depending on the element string.

Of all 22 elements only K was significantly lower in foliage from declining trees (0.77% - healthy vs 0.68% - declining, $t = 2.60$, $p \leq 0.05$). Conversely, N and P were both higher in declining tree foliage, N significantly so (1.90%-healthy vs 2.05%-declining, $t = 10.12$, $P \leq 0.05$). Calcium and Mg, two

elements under study in connection with forest decline in the NE USA and Europe, do not appear to be implicated in Muskoka. Calcium levels were only marginally lower in declining trees (with a large S.D.) and Mg levels were slightly higher in the declining population. Neither of these differences were statistically significant. The foliar elemental data were comparable with foliar concentrations reported in the literature. Foliar nutrient concentrations reflect the availability of soil nutrients, and as there was no consistent relationship between low foliar chemical levels and tree decline it was concluded site micro and macro nutrients were not limiting.

The Muskoka foliar concentrations were also comparable with an extensive chemical data base developed by on-going biogeochemical research conducted in the same vicinity by the Environment Ministry's Acidic Precipitation in Ontario Study (W. Gizyn, personal communication).

Additional foliage was collected from healthy and declining trees felled for stem analysis in early September. Leaves were sampled from the very top and very bottom of the crowns. The greatest difference in the four data sets (top vs bottom, healthy vs declining) was observed between the top and bottom of the crown. There was a definite gradient towards lower levels of virtually all elements in the upper crown foliage. The upper leaves most often displayed decline symptoms. In healthy trees P, Ca, Mg, Pb, Ni, N, B and S levels were substantially lower in upper crown foliage based on the S.D. In addition, N, B and S were considerably lower in upper crown foliage in declining trees. When the healthy and declining data sets were pooled to provide a sample population suitable for statistical testing it was observed that P, Ca, N, B, S, Pb and Ni, were significantly lower in upper crown foliage at the 5% level and Mg at the 1% level. These data are listed in Table 3.

Morrison (1985) noted a similar gradient from upper to lower crowns in sugar maple and reported comparable foliar concentrations from stands near Sault Ste. Marie in Ontario. It is known from biogeochemical research in Ontario that throughfall and stemflow in hardwood forests are nutrient enriched relative to ambient precipitation (W. Gizyn, personal communication). Foliar leaching by rainfall is assumed to be a naturally occurring and important process in nutrient cycling in the forest ecosystem.

The chemical concentrations of twigs collected from healthy and declining trees, like the foliar analysis, did not implicate site nutrient deficiencies as factors contributing to the observed tree decline. All element levels except K were similar or higher in twigs from declining trees. Iron, P and N were found to be significantly higher ($P \leq 0.05$) in twigs from declining trees.

Soil samples 0-30 cm in depth were collected from within the drip line of each of the sampled trees. Potassium was found to be significantly higher (t = 3.51, P 0.05) in soil around the declining trees. Therefore soil K was not the reason for depressed foliar K levels. There were no statistically significant differences between the healthy and declining soil data sets for the remaining 21 elements.

The root samples were divided in "fine" roots (1 to 3 mm diameter) and "terminal" roots (0.5 - 1 cm diameter). All root samples were washed for 30 minutes in a warm water ultrasonic bath to remove adhering soil particles prior to processing for analysis. The root chemical data for Muskoka are summarized in Table 4.

The chemical concentrations were marginally lower in fine roots from declining trees for all elements except K, Al, Na and Ni. The K levels in declining fine roots were 38% higher than healthy roots, although a large S.D. negated the significance of this relationship. The Al levels averaged 47% higher in fine roots from declining trees (4000 ppm - declining vs 2730 ppm - healthy, t = 2.41, p 0.05). The Al concentration of terminal roots was substantially lower than the fine roots, suggesting Al is not translocated even short distances along the root in the same concentration that it is absorbed at the root tip.

Many of the fine roots from the declining trees were dead, and root death is consistent with the observed crown decline symptoms. Dead roots in conjunction with elevated Al concentrations suggest that Al toxicity may be a causal agent. However, fine root Al concentrations were not higher in declining trees from the Thunder Bay site where the soluble Al levels determined from soil pits are much lower than in Muskoka. The soil collected from around the trees was analyzed for total, not soluble, chemical concentrations. There was no relationship between Al levels in fine roots and total soil Al at the same tree. The soil from around each tree has been re-submitted for analysis of the same parameters as the soil pit soil samples. The results (not available at the time of writing) will be examined to determine if the trees with elevated root Al levels are growing in soil with proportionately higher soil soluble Al levels.

It has been suggested that the dead root component of the root samples collected from declining trees may passively adsorb available soil ions and that this may account for the elevated Al levels in these samples. This can be discounted because passive adsorption would result in similarly elevated concentrations of light and heavy metals and halide ions. This was not apparent in tree roots from declining root samples. This suggests that Al may be selectively absorbed, although it does not appear to be translocated beyond the fine root system.

Root samples from healthy and declining trees were collected for starch analysis. The roots (less than 1 cm diameter) were extracted with ETOH and each sample's colorimetric absorbance was compared with known absorbance vs concentration curve of D-glucose to determine starch content. The root starch concentration of healthy trees averaged 12.7% and ranged from 9 to 18%. Conversely the root starch concentration of declining sugar maple trees averaged 9.7% and ranged from 3 to 14%. There was a marked tendency towards greatly reduced root starch levels in severely declining trees, although this could not be tested statistically because of the small sample population. Low root starch reserves reduces the tree's vigor which impedes its defence mechanisms and may predispose the tree to secondary pathogenic infection.

In summary, based on total chemical concentrations in the soil collected around the trees and from foliage, nutrient deficiencies were not implicated in the decline of sugar maple in Muskoka. A chemical gradient existed with increasing foliar chemical concentrations in the bottom of the crown compared to the top. This could be related to leaching by ambient rainfall. Accelerated foliar leaching by acidic precipitation could not be documented in 1984 because similar sampling of foliage from top to bottom of felled trees was not conducted in Thunder Bay, an area which receives substantially less acidic deposition than Muskoka.

Insects and Disease

Armillaria mellea was observed in all Muskoka study sites. The characteristic black shoe-string rhizomorphs of A. mellea were present on approximately 50% of the root samples collected, and occurred more frequently on declining tree roots.

A severe infestation of forest tent caterpillar occurred in the study area in 1976 and 1977. The trees at some of the sites were defoliated twice in one season. Trees stressed by defoliation are predisposed to infection by A. mellea (Wargo and Houston, 1974). Parker and Houston (1971) attributed the subsequent death of defoliated trees to A. mellea which invaded the weakened roots.

Although the total growing season (April to September) precipitation subsequent to defoliation was not significantly below normal the May 1977 rainfall was below the five percentile level. In addition, April 1976 and June 1983 received less than 50% of the 20 year mean rainfall for these months. These drought conditions occurred at critical times for tree growth. The woodlot owners indicated that tree decline began from 1978 to 1981. It would appear that repeated insect defoliation, drought stress and subsequent root infection by A. mellea were contributing factors to the present decline syndrome.

Incremental Growth Measurements

Two increment cores were taken at breast height from each of the six sample trees at each of the eight study sites. The cores were mounted, sanded and stained wth phluoroglucinol to highlight the annual growth rings. The ring widths were observed through a microscope and measured to an accuracy of 0.01 mm on a Bannister Incremental Measuring Machine interfaced with an Apple II microprocessor. Accompanying software modelled after Fayle and MacIver (1983) provided on-line ring-series graphics to continuously compare the measured cores and ensure accurate ring dating. Additional software programs transformed the actual ring width measurements into tree-ring indices as described by Fritts (1966). This is accomplished by fitting a regression line curve to each ring width series and dividing the actual ring width by each yearly value of the fitted curve. The resultant tree-ring index has a mean approximating 1.00 and a variance which is independant of tree age, position within the stem and mean growth of the tree. The individual tree ring indices were averaged to generate a sugar maple chronology for each study site, a chronology for healthy and declining tree populations and a Muskoka regional sugar maple chronology.

Indexed ring width and total growing season rainfall was not (positively) significantly related at any of the eight study sites. Although the correlation was better the relationship was still not (positively) statistically significant when total May, June and July rainfall was regressed with indexed ring-widths. These data indicate that, except in times of drought, rainfall was not a primary limiting factor to sugar maple growth in Muskoka.

Figure 1 is a histogram illustrating 10-year mean index values for the healthy and declining maple tree populations from 1905 to 1984. The tree condition, declining or healthy, is relative to observations made in the summer of 1984. For most of this century the "declining" trees were actually producing wider growth rings than the healthy trees. However in the last decade the declining trees averaged considerably less growth than the healthy trees (mean 10 year index value 0.941-declining vs 1.177-healthy). Also, the 10 year mean ring index value for the declining trees has decreased every decade subsequent to peak growth obtained in the period 1945-54. For example, from 1945 to 1954 growth rings from the declining trees averaged 25.3% wider than the healthy tree rings. From 1955 to 1964 rings from the declining trees averaged 17.6% wider. In the next 10 year period the mean ring width value was 11.7% wider than the healthy trees and from 1975 to 1984 the ring widths from the declining trees averaged 16.0% narrower than healthy tree rings. The healthy trees have not experienced a parallel trend in

reduced ring growth. In addition, the growth depression associated with the 1976/77 caterpillar defoliation was considerably more severe in the declining trees (Figure 2). Furthermore the healthy trees recovered from the defoliation producing much wider rings subsequent to the collapse of the insect population, whereas no parallel growth recovery was apparent in rings from the declining trees.

These data suggest that the current decline episode in Muskoka was likely initiated by the 1976/77 insect defoliation. Drought periods in the spring of 1976, 1977 and 1983 and infection by A. mellea hastened the decline of weakened trees. However the declining trees appear to have been growing progressively poorer for 20 years previous to the insect epidemic, suggesting that these trees may have been predisposed to decline by physiologic, genetic or environmental factors.

Summary

The current outbreak of sugar maple decline in Muskoka first became evident about 1978. Based on a study conducted by the Ontario Ministry of the Environment in 1984, decline symptoms were observed on trees throughout the Muskoka region, with no consistent pattern as to topography, aspect or site. Although some degree of tree decline was observed on maples in all age classes it was most pronounced on older trees and trees which had been tapped for maple syrup production or otherwise wounded. Site nutrient deficiencies were not implicated in the decline of sugar maple.

The soil at the Muskoka sites was acidic and contained high amounts of soluble aluminum. Declining trees in Muskoka suffered extensive root death and the fine roots had significantly higher Al concentrations than fine roots of healthy trees. Conversely, higher Al concentrations were not found in the fine roots of declining trees at the Thunder Bay site, where low amounts of soluble aluminum occurred in the soil. A foliar chemical gradient was detected with reduced elemental concentrations in the tops of the tree crowns at Muskoka. Annual growth rings for both healthy and declining trees were very narrow during two years of forest tent caterpillar defoliation. Subsequent to the collapse of the insect epidemic, growth recovered in the healthy trees but not in the declining trees. Incremental growth in the declining tree population appeared to be falling relative to the healthy trees for 20 years prior to the caterpillar infestation suggesting this group of trees may have been predisposed to decline perhaps by physiologic, genetic or environmental factors. Early season droughts during the two years of the defoliation by insects (1976 and 1977) and again in 1983 and root infections by Armillaria mellea were some of the contributing factors to tree decline.

It is apparent that the role of acidic precipitation as a contributing factor to sugar maple decline is part of a complex system. The primary mechanism of sugar maple decline is probably site specific, and may vary between individual trees and regions. At Muskoka the soils are acidic and are classified as sensitive; Al is freely available to trees and therefore the potential for indirect effects to trees exists. Higher amounts of aluminum were found in the fine roots of declining trees in Muskoka compared to healthy trees. Foliar tissue leaching and reductions in incremental growth on some trees may be environmentally related. Sugar maple decline is widespread throughout the Muskoka area and the region receives high loadings of acidic deposition (over 35 kg SO_4 in wet precipitation per ha per yr).

Conclusions

From the above, it may be tentatively concluded from the first year's study of sugar maple decline at Muskoka, that acidic precipitation is an additional stress to the severe epidemic of forest tent caterpillar in the late 1970's combined with spring droughts in 1976, 1977 and 1983. Armillaria mellea root rot, tree age and site management are also contributing factors.

Future Work

The following field studies have been planned to further investigate the acid rain/maple decline relationship. Additional sites will be established in NW Ontario on acidic soils, in SE Ontario on calcareous soils, and in SW Ontario in areas which had not been infested by the forest tent caterpillar in 1976 and 1977. Increased sampling and chemical analysis will be carried out on roots and adjacent soil to determine root/soil tree decline relationships. Extensive foliar sampling from various crown positions will be done to observe if tissue leaching is more pronounced in areas of greater acidic deposition. A controlled environment experiment is to be conducted on sugar maple trees by exposing them to simulated acid rain and ozone. These studies will be conducted by Ontario Ministry of the Environment Phytotoxicology scientists in 1985 and 1986.

In addition, two major forest research contracts will be tendered and the work conducted in 1985 and 1986. These are 1) a province wide hardwood decline survey to document which tree species are affected, and the extent and severity of decline, and 2) a dendrochronological study of sugar maple growth from calcareous and acidic soils along an acidic deposition gradient in Ontario.

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Table 1

Relationship Between Diameter Class and Tree Decline Index in Sugar Maple Permanent Observation Plots

Woodlot Owner	Woodlot Location	Mean Decline Index* per Diameter Class**					
		10-15 cm	16-20 cm	21-25 cm	26-30 cm	31-35 cm	> 35 cm
Miller	Sundridge	18.1	18.7	37.0	37.0	35.8	34.6
Fincham	Burks Falls	12.3	17.7	12.5	21.8	44.0	-
Griffith	Burks Falls	12.0	21.0	12.0	26.6	12.0	19.0
MacLachlan	Huntsville	12.0	12.0	23.3	30.3	29.0	39.2
Boothby	Dorset	14.0	12.0	26.0	26.6	30.3	12.0
Veitch	Utterson	14.2	12.5	17.0	33.2	32.0	40.0
Gibson	Gibson	17.3	19.5	24.5	19.5	14.2	34.0
Mean, Muskoka Sites		14.3	16.2	21.8	27.9	31.8	34.8
Number of Trees		39	32	24	34	29	22
% of Total Trees		21.7	17.8	13.3	18.9	16.1	12.2
Thunder Ski	Thunder Bay	10.5	11.0	26.2	33.7	25.3	29.7

* Decline Index gradient defined in text.

** measured as Diameter Breast Height in cm.

Decline Index = 21.719 + 0.112 Diameter Breast Height ($t = 2.748$, $p \leq 0.01$, all sites combined)

Table 3

Soil Sensitivity Parameters (Mineral Soil)

Woodlot Location	Decline Index	Soil Classification	pH*	$CaCO_3$ %	CEC meq/100g	BS %	Exch Bases meq/100g	Sand %	Sol Al* ug/g	Sol SO_4* ug/g	Sensitivity*** Rating
Miller	34.7	Sombric Ferro-humic Podzol	4.4-5.2	ND**	0.61-2.6	22-34	0.14-0.88	68-98	5-19	8-24	sensitive
MacLachlan	27.2	Sombric Humo-ferric Podzol	4.9-5.1	ND	0.37-1.5	17-28	0.00-0.29	37-89	7-25	10-18	sensitive
Griffith	26.6	Gleyed Ferro-humic Podzol	4.8-4.9	ND	0.35-1.9	4.4-21	0.04-0.33	65-95	6-33	10-19	sensitive
Gibson	22.4	Sombric Ferro-humic Podzol	4.2-5.2	ND	0.45-2.3	11-27	0.05-0.33	85-95	7-33	3-19	sensitive
Thunder Bay	21.1	Gleyed Eutric Brunisol	6.3-6.9	0.04-0.17	5.7-8.6	97-100	5.7-8.6	44-80	0.08-0.26	4-6	moderately sensitive
Veitch	21.0	Gleyed Ferro-humic Podzol	4.0-5.0	ND	0.80-1.8	27-38	0.22-0.65	67-80	12-20	18-40	sensitive
Boothby	19.6	Sombric Ferro-humic Podzol	4.8-5.3	ND	0.50-2.7	29-60	0.15-1.6	51-80	6-16	7-25	sensitive
Fincham	17.6	Sombric Humo-ferric Podzol	4.8-5.0	ND	0.55-3.2	16-44	0.18-1.42	32-85	8-30	10-27	sensitive

* pH - (H_2O)
Sol Al - $CaCl_2$ extracted. Sol SO_4 - water extracted.
** ND - Not Detected
*** based on base content (the product of CEC and BS, Wang and Coote, 1981).

Table 3

Foliar Chemical Concentrations of Mature Sugar Maple Trees (both declining and healthy) from the Muskoka Region of Ontario

Element	Foliar Chemical Concentration*		Statistical Significance**
	Top of Crown	Bottom of Crown	
Fe	109	95	NS
Mn	1210	1630	NS
P	0.14%	0.18%	5% (t = 3.06)
N	1.92%	2.28%	5% (t = 2.79)
Al	70	60	NS
B	63	81	5% (t = 2.37)
Ca	8240	12000	5% (t = 2.84)
Cd	0.3	0.4	NS
Cl	0.04%	0.05%	NS
Cr	1	2	NS
Cu	6	7	NS
F	< 1	< 1	-
K	0.77%	0.89%	NS
Mg	1010	1680	1% (t = 3.34)
Mo	< 0.5	< 0.5	-
Na	15	12	NS
Ni	1.7	2.4	5% (t = 2.84)
Pb	1.7	2.2	5% (t = 2.73)
S	0.18%	0.22%	5% (t = 2.92)
V	< 1	< 1	-
Zn	27	29	NS

* not-washed, oven-dried, ppm (except % where noted), mean of 20 replications

** paired t test.

Table 4

Root Chemical Concentrations of Healthy and Declining Sugar Maple Trees - Muskoka Region

Element	Chemical Concentration*				Statistical Significance**
	Healthy Tree Roots		Declining Tree Roots		
	1-3 mm	0.5-1 cm	1-3 mm	0.5-1 cm	
Fe	785	268	730	350	NS
Mn	232	332	189	302	NS
P	0.60%	0.50%	0.50%	0.40%	5% (t = 2.45)
N	0.77%	0.45%	0.62%	0.53%	NS
Al	2730	2200	4000	1880	5% (t = 2.41)
B	11	11	10	12	NS
Ca	5200	6370	4600	6330	NS
Cd	1.2	0.8	1.0	0.9	NS
Cl	0.01%	0.01%	0.01%	0.01%	-
Cr	1	1	1	1	NS
Cu	10	4	7	3	NS
F	< 1	< 1	< 1	< 1	-
K	0.16%	0.20%	0.22%	0.10%	NS
Mg	890	760	745	840	NS
Mo	< 0.5	< 0.5	< 0.5	< 0.5	-
Na	37	17	58	23	5% (t = 2.93)
Ni	5	3	8	4	NS
Pb	5	2	3	2	NS
S	0.08%	0.03%	0.07%	0.03%	NS
V	2	1	3	1	NS
Zn	69	42	56	40	NS

* washed, oven-dried, ppm (except % where noted) mean of 10 replications.

** paired t test, mean Healthy vs mean Declining

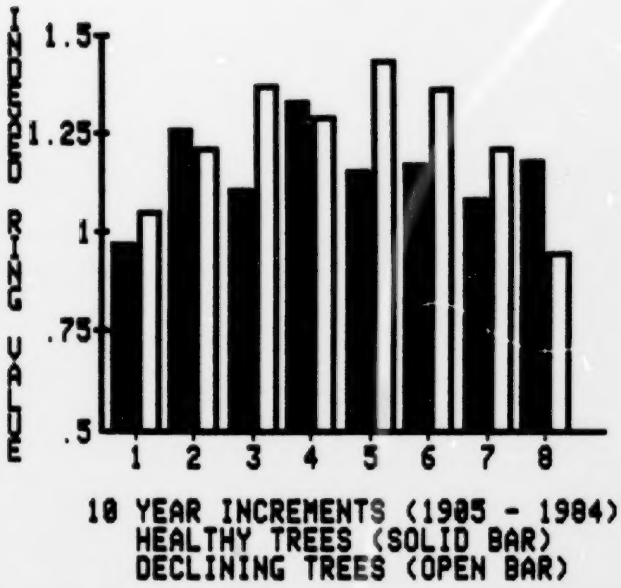

Figure 1: Incremental Growth of Healthy and Declining Sugar Maple Trees from Muskoka, 1905 to 1984.

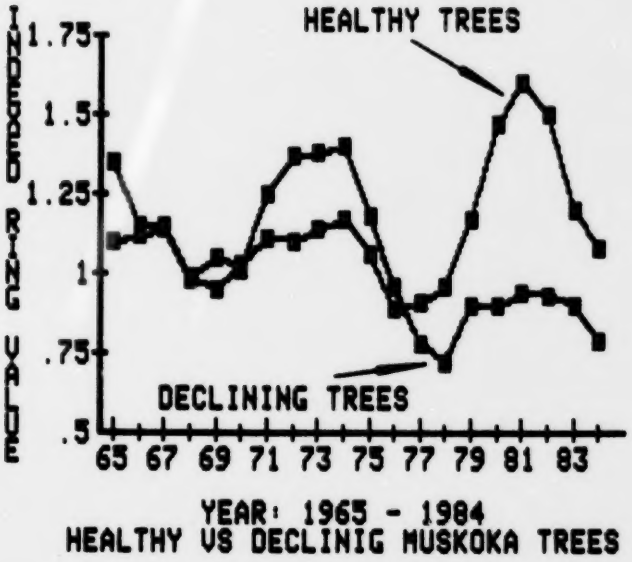

Figure 2: Annual Growth of Healthy and Declining Sugar Maple Trees from Muskoka, 1965 to 1984. The Area Sufferred an Outbreak of Forest Tent Caterpillar from about 1975 to 1978.